Recent progress and trends in development of high-field HTS coated conductors at Bruker HTS; interaction with EASITrain project

BRUKER HTS GmbH
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1. Processing route and CC architecture
2. Performance of DD-HTS coated tapes
3. 4.2 K via 77 K characterization
4. EASITrain: expected input to tape processing
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BHTS pilot-line plant with more than 2000sqm operation area, located in the Industrial Park North of Alzenau, Germany

Manufacturing of HTS coated conductors tailored for it’s application at ultra-high magnetic fields at intermediate and low temperatures

Processing route based on vacuum coating technology (e.g. Pulsed Laser Deposition), capability to process 4 mm wide HTS tapes with a max. single piece tape length of 600 m (12mm wide HTS tapes with a max. single piece tape length of 100 m)
## Processing Technology

<table>
<thead>
<tr>
<th>PROCESSING CHAIN OF HTS PILOT-LINE PRODUCTION</th>
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<tbody>
<tr>
<td>SUBSTRATE PREPARATION (SUB)</td>
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<tr>
<td>BUFFER LAYER COATING (ABAD)</td>
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<tr>
<td>HTS LAYER COATING (PLD)</td>
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<td>METAL COATING (MET)</td>
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<tr>
<td>COPPER PLATING (PLA)</td>
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<tr>
<td>FINAL TAPE INSPECTION (INS)</td>
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- Wet chemical processes: SUB, CAP
- Vacuum coating processes: ABAD, PLD, MET
- Ic in-field measurements at 4.2K: INS

Pulsed Laser Deposition PLD production coater
Pulsed Laser Deposition Principle

- Manufacturing of coated conductors (HTS 2G) tailored for its application in high magnetic fields
- Drum based tape transport
- Equilibrium heating (QEH) → “Hot wall reactor” in deposition zone
- Quick substrate/drum rotation combined with movable deposition zone via laser beam scans.
- Oscillation of oxygen pressure during PLD.
Nano Structure of DD-HTS Layer

DOUBLE DISORDERED DD-YBCO FILMS

- Further structural analysis of YBCO films show strongly inclined nano-columns of extrinsic phase
- Possible explanation is the observed PLD laser plume lateral flow of material deflected and “guided” by substrate surface including etching effects (dev. model fits well to data)

“Firework” structure of extrinsic phase, columnar nano-chains tilting to 90°

a, b – YBCO layer cross-section
c, d – views along c-axis
BRUKER HTS
HIGH-FIELD HTS COATED CONDUCTORS

Tape Performance

Outstanding engineering current density

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>$J_e(18T)$</td>
<td>454.11</td>
</tr>
<tr>
<td>$I_c$</td>
<td>0.09</td>
</tr>
<tr>
<td>$t$, mm</td>
<td>4</td>
</tr>
<tr>
<td>$w$, mm</td>
<td>4</td>
</tr>
<tr>
<td>$S$, mm$^2$</td>
<td>0.36</td>
</tr>
<tr>
<td>$J_e$, A/mm$^2$</td>
<td>1.26142</td>
</tr>
</tbody>
</table>

- This $J_e$ indicates opportunity to reach very high current density.

It should not be understood in a way that this number is well-reproducible at the moment.

$D.\ Abrainov,\ G.\ Bradford,\ J.\ Jaroszynski,\ and\ D.C.\ Larbalestier,\ June\ 2018$
1. Achieved high $I_c$-s in long-length tapes originate from well-established and stable processing at Bruker HTS.

2. Nevertheless the characterization-processing feedback represents an issue for DD-HTS tapes because:

   - characterization of $I_c$ at 77 K, SF does not correlate with $I_c$-s at 4.2 K, while

   - characterization of long tapes at 4.2 K is unrealistic because of LHe2 costs.
Inhomogeneity of $I_c$ in long tape

![Graph showing inhomogeneity of $I_c$ in long tape.](image-url)
Correlation or anticorrelation in inhomogeneous tape?

NON-UNIFORMITIES

- Lift factor as a ratio of $I_c(18T, 4.2K, B//c)$ to $I_c(SF, 77K)$ is shown below.
- No obvious correlation of these $I_c$-s was observed.

![Graph showing correlation](image)
Expected input of the EASITrain and a new national project

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
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<tbody>
<tr>
<td>Correlation study of $I_c(B,T)$ in DD superconductors</td>
<td>Parametrization of $I_c(B,T)$ in DD superconductors</td>
<td>Evaluation of $I_c(4.2K)$ via $I_c(3T, 77K)$</td>
<td>Development of criteria</td>
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</table>

Supported in part via **EASITrain project**; Under interaction with Vienna University of Technology (AT), M.Eisterer

- **Steps C-D or B-C-D** to be fully developed and integrated in the processing chain
- **Steps A, B and partly C** are already developed within EASITrain Project
Expected processing chain with new QA

\[ U_{\text{tot}} = \frac{U_{\text{cr}}}{L} \int_{0}^{L} \left[ \frac{I}{I_c(B(x))} \right]^{n(B(x))} \, dx \]
(a) V-I curves observed at critical current measurements in non-treated sample at SF (1) and 0.4 T (3) at field oriented perpendicularly to the tape and localized within ~5 mm long area between voltage probes. Mechanically treated (scratched) tape exhibits a ~13% deterioration of critical current at SF (2) and 4% deterioration (4) when the field is applied. V-I curve (4a) results from modeling via equation 1. The dashed line (5) indicates transition criterion. (b) View of investigated sample. [Usoskin, Betz, Gnilsen et al 2019 Supercond. Sci. Technol. https://doi.org/10.1088/1361-6668/ab2c8a]
Expected input of the EASITrain and a new national project

Ultimate goal is to provide a new art of quality assurance which enables
- higher processing yield and
- narrowing of Ic scattering in high magnetic field tapes

Continuous reduction of Ic scatter in 600m batch size pilot production
SUMMARY

• High performance of DD-YBCO coated conductors was confirmed via quality of routinely processed, up to 600 m long tapes as well as up to 100 m, 12 mm wide tapes

• Highest Je of 1261 A/mm² at 4.2K, 18 T, B//c was recently achieved

• In PLD/ABAD processing, new factors that determine instant deposition temperature and LFL - based PLD were found.

• Advanced methodology for quality assurance has to be developed within EASITrain and a new national project

• Correlation study and parametrization of Ic(B,T) in DD superconductors are performed already within EASITrain (two full-volume manuscripts are submitted to high ranking journals)